Project Report: The Planetary Context of Biological Evolution

Project Investigator:	***Andrew Knoll***

Project Progress

The Harvard NAI team was constituted in 1998 as an interactive group of biogeochemists, paleontologists, sedimentary geologists, geochemists, and tectonic geologists assembled with the common goal of understanding the coevolution of life and environments in Earth history. In Year 6, the final year of NAI activity for the Harvard group, the team completed research in its core areas of inquiry: environmental evolution in the early Paleoproterozoic (2400–2200 Ma) when oxygen began to accumulate in the atmosphere and surface ocean; the terminal Proterozoic and Early Cambrian intervals (750–525 Ma) when animal life radiated; the Permo–Triassic boundary (251 Ma) when mass extinction removed some 90 percent of Earth's species diversity, permanently altering the course of evolution; the recognition and interpretation of molecular and isotopic biomarkers; and the astrobiological evaluation of a terrestrial analog for iron oxide and sulfate rocks recently discovered at Meridiani Planum, Mars. Our efforts in Earth history and evolution highlight the importance of Earth's physical development for the course of biological evolution –– the planetary context of evolution is likely to be a major theme of astrobiological inquiry wherever life may be found. Our paleobiological and geochemical analyses of ancient rocks and our research on the generation of molecular and isotopic biosignatures further provide the tools by which the search for life beyond the Earth will be conducted. Finally, our research on iron/sulfate rocks on Earth will help to guide continuing astrobiological investigation of the Martian surface, including projected sample return.

Highlights

- Analyses of mass independent sulfur isotopic fractionation in radiometrically calibrated sedimentary successions from South Africa show that Earth's atmosphere and surface oceans first began to accumulate oxygen between 2.45 and 2.32 billion years ago.
- Analyses of Mo–isotopes in mid–Proterozoic sedimentary rocks show that oxygen levels in the oceans remained low 1.5 billion years ago, with anoxic deep waters exhibiting a broader distribution that they have in oceans of the past 500 million years.

- Analyses of sulfur isotopes in stratigraphically well constrained sedimentary successions from southern Africa, Canada, and Australia indicate that levels of oxygen and sulfate in the oceans increased substantially ca. 580 million years ago, just before the initial appearance of large animals.
- Radiometric analyses of ash beds in key sedimentary successions calibrate the climatic and biological history of the Neoproterozoic and Cambrian Earth. Dates of 635+/– 1.2 million years, 580 +/1 million years, and 575+/1 million years constrain the ages of the younger global Neoproterozoic ice age, a further regionally distributed ice age, and the evolution of large animals, respectively.
- Combined stratigraphic and isotopic geochemical research have yielded a new understanding of Earth's Neoproterozoic and Cambrian carbon cycle, providing an important means of understanding the relationships among life, climate, and biogeochemical cycles 800–530 million years ago.
- Geochemical and paleobiological analysis of modern and Neogene iron deposits of the Rio Tinto basin, southwestern Spain, demonstrate the astrobiological potential of sample return from Meridiani Planum, Mars.

Roadmap Objectives

- ***Objective No. 1.1:*** Models of formation and evolution of habitable planets
- ***Objective No. 1.2:*** Indirect and direct astronomical observations of extrasolar habitable planets
- ***Objective No. 2.1:*** Mars exploration
- ***Objective No. 4.1:*** Earth's early biosphere
- ***Objective No. 4.2:*** Foundations of complex life
- ***Objective No. 6.1:*** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- ***Objective No. 7.2:*** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	***Mission Name (for class 1 or 2) OR Concept (for class 3)***	***Type of Involvement*****
1	Mars MER	Science Team Member
2	Mars Sample Return	Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF,

Mars Lander 2009)
3. Long−lead future mission / societal issues (e.g., far−future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co−I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Knoll and Grotzinger are memebrs of the MER science team. Work by a number of team memebrs (Knoll, Grotzinger, Hayes, Holland, Summons, and Anbar will feed directly into the choice of site and choice of analyses for Mars sample return.

Cross Team Collaborations

See submitted report. Collbaorations ending this year include work with memebrs of Penn State, Carnegie, and NASA Ames teams, as well as the Spanish CAB and the Australian Centre for Astrobiology.